OUTCOME-3& 4

3. Explain the concept of two port networks.

4. Determine Impedance, Admittance, Hybrid and ABCD parameters of two port networks.

OBJECTIVES:

- Define the two-port network parameters.
- Write in terms of matrix equation the two-port network parameters.
- Establish relationship between impedance and admittance matrix of a two-port network.
- Calculate *Z*-parameters and *Y*-parameters of two-port networks.
- Define and represent hybrid or *h*-parameters of two-port networks.
- Define and represent inverse hybrid or *g*-parameters.
- Define transmission parameters or *A*, *B*, *C*, *D* parameters.
- Calculate for a given network the *A*, *B*, *C*, *D* parameters.
- Establish correlation between the network parameters. Convert *A*, *B*, *C*, *D* parameters into *h*-parameters.
- Explain two-port reciprocal network and symmetrical network.
- Calculate the *Z*-parameters and *Y*-parameters of interconnected two-port networks.
- Represent two-port networks as *T*-circuit and π-circuit.
- Explain the concept of image impedance of a network.

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1. INTRODUCTION

- An electrical network may be represented by a rectangular block having pairs of terminals. Each pair of terminals is called a port. A pair of terminals at which signal enters is called a PORT.
- Similarly, a pair of terminals through which signal leaves is called another port. In a TWO-PORT NETWORK, signal enters the input port and after getting processed come out at the other port.
- For EXAMPLE, consider a Public Address System (PA system). The system comprises a microphone, an amplifier and a loudspeaker. The audio-amplifier receives through the microphone signals and sends the amplified signals through the loudspeaker. The audio-amplifier is, therefore, a two-port network.

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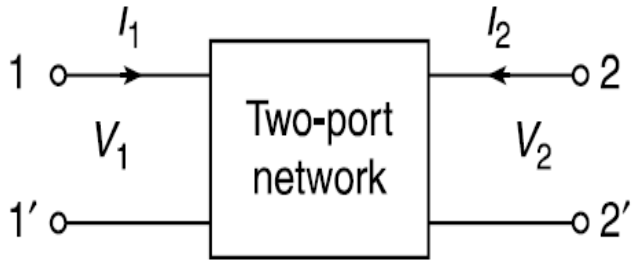
- A port is defined as any pair of terminals into which signal is received or from which signal is taken out.



Block Diagram Representation of a Two-port Network

- Fig. 1 shows a two-port network having two ports, namely I-l' and 2-2'.
- The block may represent a communication system, an electronic system, an electrical transmission or distribution system, etc.
- Terminals 1-1' is a pair that constitutes a port. Similarly, the pair of terminals 2-2' constitutes Representation of another port.
- The voltage and current at the input terminals are V_1, and I_1, and at the output port are V_2, and I_2,, respectively.
- It has been assumed that both I_1, and I_2, are entering the network through terminals1 and 2, respectively. Thus, there are four variables, that is, V_1, I_1, V_2 and I_2 Out of these four variables, two are dependent variables and the other two are independent variables.
- In a two-port network, a variable pair is related to the other variable pair by a pair of linear equations formed with the help of network parameters. The different network parameters that can be used for the formulation of simultaneous equations .

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TWO-PORT NETWORK PARAMETERS

In a two-port network, there are four variables. Arbitrarily, any two of these variables can betaken as independent variables. Open-circuit impedance parameters or Z-parameters are calculated by considering V_1, and V_2, as dependent variables and I_1, and I_2, as independent variables.

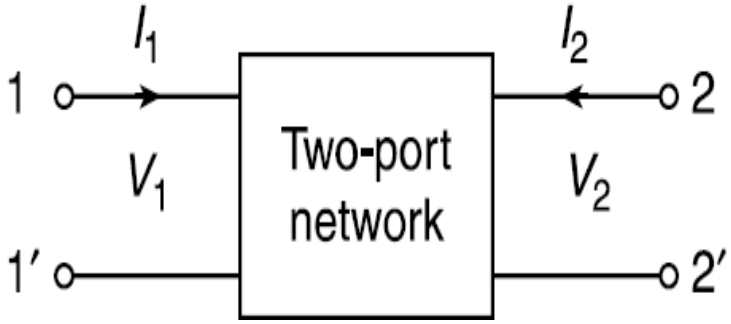
Similarly, I_1, and I_2, can be taken as dependent variables and V_1, and V_2, are taken as independent variables to determine the short-circuit admittance or parameters. Determine The Two-port Network Parameters Of Different Circuit Configurations.

2.1 Open-circuit Impedance-parameters or Z-parameters:

A two-port network is redrawn as in Fig.

Here, we consider V_1, and V_2, as dependent variables

and I_1 and I_2, as independent variables.



Let Z_{11}, Z_{12}, Z_{21} and Z_{22} are the Z-parameters.

The voltage V_1, and V_2, in terms of I_1 and I_2 are expressed as follows:

$$V_1 = Z_{11}I_1 + Z_{12}I_2 \quad \text{----------1}$$

$$V_2 = Z_{21}I_1 + Z_{22}I_2 \quad \text{----------2}$$

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In terms of matrix equations, the following can be obtained:

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} \quad \text{----------3}$$

where matrix $\begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix}$ is called the impedance matrix.

The individual Z-parameters can be found as indicated in the following.

When the output port is open-circuited, that is, when $I_2 = 0$, the equation (1) will be as follows:

$$V_1 = Z_{11}\, I_1 + 0$$

That is $Z_{11} = V_1/I_1$ ----------4

From equation (2), we will have the following form:

$$V_2 = Z_{21}\, I_1 + 0$$

That is $Z_{21} = \frac{V_2}{I_1}$ ---------- 5

When the input port is open-circuited, that is, when $I_1 = 0$, then equation (1) will be given as follows:

$$V_1 = 0 + Z_{12}\, I_2 \quad \text{that is} \quad Z_{12} = \frac{V_1}{I_2}$$ ----------6

and from equation (2), we will have the following equation:

$$V_2 = 0 + Z_{22}\, I_2 \quad \text{that is} \quad Z_{22} = \frac{V_2}{I_2}$$ ----------7

Therefore, the Z-parameters of a two-port network are as follows:

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All these parameters are also called open-circuit impedance parameters.

Z_{11}, is known as the driving-point impedance at the input port, when output port is open-circuited.

Z_{21}, is known as the transfer impedance at the input port, when output port is open-circuited.

Z_{22}, is known as the driving-point impedance at the output port, when input port is open-circuited.

Z_{12}, is known as the transfer impedance at the output port, when input port is open-circuited.

2.2 SHORT-CIRCUIT ADMITTANCE PARAMETERS:

The admittance parameters are also called Y-parameters. To determine Y-parameters, V_1, and V_2, are taken as independent variables and I_1, and I_2, as dependent variables. Port currents I_1,and I_2, are expressed in terms of the voltages V_1 and V_2. The network equations are written as follows:

$$I_1 = Y_{11} V_1 + Y_{12} V_2 \qquad \text{----------1}$$

$$I_2 = Y_{12} V_1 + Y_{22} V_2 \qquad \text{----------2}$$

The equations can be represented in matrix form as follows:

$$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} \qquad \text{----------3}$$

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where Y_{11}, Y_{12}, Y_{21}, and Y_{22} are admittance parameters, and these can be determined as in the following.

When output port is short-circuited, that is, when $V_2 = 0$, equation (1) will give the following form:

$$I_1 = Y_{11}V_1 + 0 \quad \text{or} \quad Y_{11} = \frac{I_1}{V_1}$$ -------3

and equation (2) will be calculated as follows:

$$I_2 = Y_{21}V_1 + 0 \quad \text{or} \quad Y_{21} = \frac{I_2}{V_1}$$ -------4

When the input port is short-circuited, that is, when $V_1 = 0$, equation (1) can be written as in the following:

$$I_1 = 0 + Y_{12}V_2 \quad \text{or} \quad Y_{12} = \frac{I_1}{V_2}$$ ------5

and equation (2) will be given as follows:

$$I_2 = 0 + Y_{22}V_2 \quad \text{or} \quad Y_{22} = \frac{I_2}{V_2}$$ ----------6

These Y-parameters are also called short-circuit admittance parameters, as these are found by short-circuiting the input port or the output port. Summary of short-circuited admittance parameters is provided below.

$Y_{11} = \left.\frac{I_1}{V_1}\right|_{V_2 = 0}$ is also known as the driving-point admittance at input port with output port short-circuited.

$Y_{21} = \left.\frac{I_2}{V_1}\right|_{V_2 = 0}$ is also known as the transfer admittance at input port with output port short-circuited.

$Y_{12} = \left.\frac{I_1}{V_2}\right|_{V_1 = 0}$ is also known as the transfer admittance at output port with input port short-circuited.

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$Y_{22} = \left.\frac{I_2}{V_2}\right|_{V_1 = 0}$ is also known as the driving-point admittance at output port with input port short-circuited.

2.3 RELATIONSHIP BETWEEN IMPEDANCE AND ADMITTANCE MATRIX

$$[Z] = [Y]^{-1}$$

or

$$[Y] = [Z]^{-1}$$

That is,

$$\begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix}^{-1}$$

$$= \frac{\text{adjoint of } \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix}}{\begin{vmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{vmatrix}}$$

$$= \frac{\begin{bmatrix} Y_{22} & -Y_{12} \\ -Y_{21} & Y_{11} \end{bmatrix}}{|Y|} = \begin{bmatrix} \frac{Y_{22}}{|Y|} & \frac{-Y_{12}}{|Y|} \\ \frac{-Y_{21}}{|Y|} & \frac{Y_{11}}{|Y|} \end{bmatrix}$$

where $|Y|$ is the determinant of Y-matrix.

Similarly,

$$\begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix}^{-1}$$

$$= \frac{\text{adjoint of } \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix}}{\begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix}}$$

$$= \frac{\begin{bmatrix} Z_{22} & -Z_{21} \\ -Z_{12} & Z_{11} \end{bmatrix}^T}{|Z|}$$

$$= \frac{\begin{bmatrix} Z_{22} & -Z_{12} \\ -Z_{21} & Z_{11} \end{bmatrix}}{|Z|} = \begin{bmatrix} \frac{Z_{22}}{|Z|} & -\frac{Z_{12}}{|Z|} \\ \frac{-Z_{21}}{|Z|} & \frac{Z_{11}}{|Z|} \end{bmatrix}$$

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Summarising,

$$\begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} = \begin{bmatrix} \frac{Y_{22}}{|Y|} & \frac{-Y_{12}}{|Y|} \\ \frac{-Y_{21}}{|Y|} & \frac{Y_{11}}{|Y|} \end{bmatrix}$$

and

$$\begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix} = \begin{bmatrix} \frac{z_{22}}{|z|} & \frac{-z_{12}}{|z|} \\ \frac{-z_{21}}{|z|} & \frac{z_{22}}{|z|} \end{bmatrix}$$

where $|Y| = \begin{vmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{vmatrix}$, that is, determinate of Y-matrix.

and $|Z| = \begin{vmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{vmatrix}$, that is, determinant of Z-matrix.

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2.4 HYBRID OR H-PARAMETERS

Hybrid parameters: V_1, and I_2, are taken as dependent variables. In this case, network equations can be written as follows:

$$V_1 = h_{11} I_1 + h_{12} V_2 \quad \text{----------1}$$

$$I_2 = h_{12} I_1 + h_{22} V_2 \quad \text{----------2}$$

Or the matrix form is given as in the following:

$$\begin{bmatrix} V_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ V_2 \end{bmatrix} \quad \text{----------3}$$

h-parameters are found as in the following: It is clear from equations (1) and (2),h-parameters can be found by substituting $I_1 = 0$ or $V_2 = 0$, that is, input port open-circuited or output port short-circuited.

When output is short-circuited, that is, V2, = 0

Equation (1) gives $V_1 = h_{11} I_1 + 0.$ Hence, $h_{11} = \frac{V_1}{I_1}$

Equation (2) gives $I_2 = h_{21} I_1 + 0.$ Here, $h_{21} = \frac{I_2}{I_1}$

When input is open-circuited, that is, $I_1 = 0$.

Equation (1) gives $V_1 = 0 + h_{12} V_2$ Hence, $h_{12} = \frac{V_1}{V_2}$

Equation (2) gives $I_2 = 0 + h_{22} V_2$, Here, $h_{22} = \frac{I_2}{V_2}$

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Therefore, the -parameters are as follows:

$$h_{11} = \left.\frac{V_1}{I_1}\right|_{V_2 = 0}$$ is also known as short-circuited input impedance parameter, in Ω.

$$h_{12} = \left.\frac{V_1}{V_2}\right|_{I_1 = 0}$$ is also known as open-circuited reverse voltage gain, dimensionless.

$$h_{21} = \left.\frac{I_2}{I_1}\right|_{V_2 = 0}$$ is also known as short-circuited current gain, dimensionless.

$$h_{22} = \left.\frac{I_2}{V_2}\right|_{I_1 = 0}$$ is also known as open-circuited output admittance in mho, ℧.

Since all the four parameters are of different types, these are known as hybrid or *h*-parameters.

2.5 Inverse Hybrid or g-Parameters

When I_1, and V_2, are taken as dependent variables. The network equations can be written as in the following:

$$I_1 = g_{11} V_1 + g_{12} I_2 \quad \text{----------1}$$

$$V_2 = g_{21} V_1 + g_{22} I_2 \quad \text{----------2}$$

Or the equations can be given in the matrix form as follows:

$$\begin{bmatrix} I_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix} \begin{bmatrix} V_1 \\ I_2 \end{bmatrix} \quad \text{----------3}$$

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The inverse #-parameters can be defined/determined by the following: Substituting V_1,=0 or I_2,=0

That is, input port short circuited or output port open circuited. When output port is open-circuited, that is, when I_2, = 0

Equation (1) gives $I_1 = g_{11}V_1 + 0$ ----------4 Or $g_{11} = \frac{I_1}{V_1}$

Equation (2) gives $V_2 = g_{21}V_1 + 0$ ----------5 Or $g_{21} = \frac{V_2}{V_1}$

When input port is short-circuited, that is, when V1, = 0 Equation (1) gives $I_1 = 0 + g_{12}I_2$ ----------6 Or $g_{12} = \frac{I_1}{I_2}$

Equation (2) gives $V_2 = 0 + g_{22}I_2$ ----------7 or $g_{22} = \frac{V_2}{I_2}$

Therefore, g-parameters are shown as in the following:

$$g_{11} = \left.\frac{I_1}{V_1}\right|_{I_2 = 0}$$

$$g_{12} = \left.\frac{I_1}{I_2}\right|_{V_1 = 0}$$

$$g_{21} = \left.\frac{V_2}{V_1}\right|_{I_2 = 0}$$

$$g_{22} = \left.\frac{V_2}{I_2}\right|_{V_1 = 0}$$

The h and g matrices are the inverse of each other. That is

$$[h] = [g]^{-1}$$

$$\begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} = \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix}^{-1}$$

$$= \begin{bmatrix} \frac{g_{22}}{|g|} & \frac{-g_{12}}{|g|} \\ \frac{-g_{21}}{|g|} & \frac{g_{11}}{|g|} \end{bmatrix}$$

Where |g| is the determinant, for example, matrix [g]

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2.6 TRANSMISSION PARAMETERS

When V_1, and I_1, are taken as dependent variables, the network equations can be written as follows:

$$V_1 = AV_2 - BI_2 \quad \text{----------1}$$

$$I_1 = CV_2 - DI_2 \quad \text{----------2}$$

Or they can be represented in matrix form as follows:

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_2 \\ -I_2 \end{bmatrix} \quad \text{----------3}$$

The A, B, C and D parameters or transmission parameters (T-parameters) are defined as in the following:
From equation (1) and equation (2), we get the following form:

$$\frac{1}{A} = \left.\frac{V_2}{V_1}\right|_{I_2 = 0}$$, this is also known as open-circuit voltage gain.

$$\frac{1}{B} = \left.\frac{-I_2}{V_1}\right|_{V_2 = 0}$$, this is called as short-circuit transfer admittance.

$$\frac{1}{C} = \left.\frac{V_2}{I_1}\right|_{I_2 = 0}$$, this is known as open-circuit transfer impedance.

$$\frac{1}{D} = \left.\frac{-I_2}{I_1}\right|_{V_2 = 0}$$, this is called as short-circuit current gain.

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2.7 INVERSE TRANSMISSION PARAMETERS

When V_2, and I_2, are taken as dependent variables: The two-port network equations can be written as in the following:

$$\begin{bmatrix} V_2 \\ I_2 \end{bmatrix} = \begin{bmatrix} A^1 & B^1 \\ C^1 & D^1 \end{bmatrix} \begin{bmatrix} V_1 \\ -I_1 \end{bmatrix} \qquad \text{----------1}$$

where A', B', C' and D' are inverse transmission parameters.

From the matrix form, inverse transmission parameters can be defined as follows:

$$\frac{1}{A^1} = \frac{V_1}{V_2}\bigg|_{I_1 = 0}$$

$$\frac{1}{B^1} = \frac{-I_1}{V_2}\bigg|_{V_1 = 0}$$

$$\frac{1}{C^1} = \frac{V_1}{I_2}\bigg|_{I_1 = 0}$$

$$\frac{1}{D^1} = \frac{-I_1}{I_2}\bigg|_{V_1 = 0}$$

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3 CORRELATION OF TWO-PORT NETWORK PARAMETERS

3.1 Conversion of Y-parameters to Z-parameters.

We can find the Z-parameters from Y-parameters as follows:

$$[I] = [Y][V]$$

and

$$[V] = [Z][I] = [Y]^{-1}[I]$$

So

$$[Z] = [Y]^{-1}$$

Hence

$$\begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix}^{-1} = \frac{1}{|Y|}\begin{bmatrix} Y_{22} & -Y_{12} \\ -Y_{21} & Y_{11} \end{bmatrix}$$

where

$$|Y| = \begin{vmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{vmatrix}$$

3.2 Conversion of A, B, C and D or t-Parameters to h-Parameters

Let us find t-parameters in terms of h-parameters. We have the following form:

$$V_1 = h_{11}I_1 + h_{12}V_2 \quad \text{----------1}$$

$$I_2 = h_{21}I_1 + h_{22}V_2 \quad \text{----------2}$$

From equation (2), we get I_1, as in the following:

$$I_1 = -\frac{h_{22}}{h_{21}}V_2 + \frac{I_2}{h_{21}} \quad \text{---------3}$$

Substituting equation (3) in equation (1), V_1, can be calculated as follows:

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$$V_1 = h_{11}\left[\frac{-h_{22}}{h_{21}}V_2 + \frac{I_2}{h_{21}}\right] + h_{12}V_2$$

$$= \frac{-h_{11}h_{22}}{h_{21}}V_2 + \frac{h_{11}}{h_{21}}I_2 + h_{12}V_2$$

$$= \left[\frac{-h_{11}h_{22}}{h_{21}} + h_{12}\right]V_2 + \frac{h_{11}}{h_{21}}I_2$$

Or

$$V_1 = \left[\frac{-h_{11}h_{22} + h_{12}h_{21}}{h_{21}}\right]V_2 + \frac{h_{11}}{h_{21}}I_2 \quad \text{----------4}$$

Comparing equation (3) and (4) with the following general equations of A, B, C and D parameters, we get the following:

Where

$$V_1 = AV_2 - BI_2$$

$$I_1 = CV_2 - DI_2$$

$$A = \frac{-|h_{11}h_{22} - h_{12}h_{21}|}{h_{21}} = \frac{-|h|}{h_{21}}$$

$$B = \frac{-h_{11}}{h_{21}}$$

equation (4)

$$C = \frac{-h_{22}}{h_{21}}$$

$$D = -\frac{1}{h_{21}}$$

from equation (3)

$$|h| = \begin{vmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{vmatrix}$$

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NUMERICAL QUESTIONS

1. Find Z-parameters

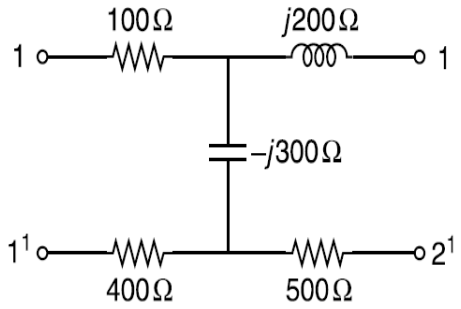

Figure 11.35

[**Ans.** $Z_{11} = 500 - j300\ \Omega, Z_{22} = 500 - j100\ \Omega, Z_{12} = Z_{21} = -j300\ \Omega$]

2. Find Y- and Z-parameters.

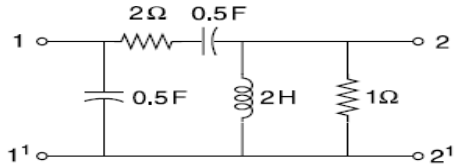

Figure 11.36

[**Ans.** Y-parameters:

$$Y_{11} = \frac{s(s+2)}{2(s+1)}, \quad Y_{22} = \frac{3s^2+3s+1}{2s(s+1)}$$

$$Y_{12} = Y_{21} = \frac{-s}{2(s+1)}$$

Z-parameters:

$$Z_{11} = \frac{2(3s^2+3s+1)}{s(3s^2+5s+2)}, \quad Z_{22} = \frac{2s(s+2)}{3s^2+5s+2}$$

$$Z_{12} = Z_{21} = \frac{2s}{3s^2+5s+2}$$

]

3. Find admittance parameters

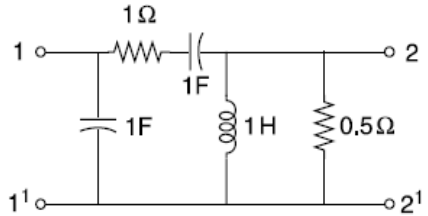

Figure 11.37

[

$$Y_{11} = \frac{s(s+2)}{s+1}$$

Ans. $Y_{12} = Y_{21} = \frac{-s}{s+1}$

$$Y_{22} = \frac{3s^2+3s+1}{s(s+1)}$$

]

4. Find Y- and Z-parameters

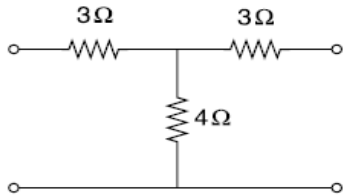

Figure 11.38

[**Ans.** Z-parameters: $Z_{11} = 7 = Z_{22}$

$Z_{12} = Z_{21} = 4$

Y-parameters: $Y_{11} = Y_{22} = \frac{7}{33}$

$Y_{12} = Y_{21} = \frac{-1}{11}$

]

5. Find Z-parameters

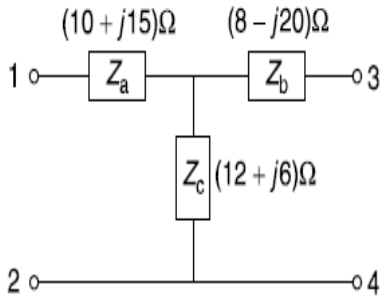

Figure 11.39

[**Ans.** $Z_{11} = 22 + j21, Z_{12} = Z_{21} = 12 + j6, Z_{22} = 20 - j14$]

6. Find Z-parameters

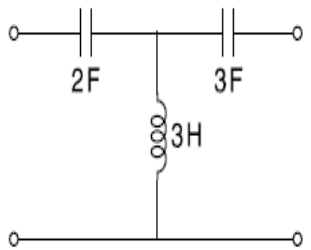

Figure 11.40

$$\left[\text{Ans. } Z_{11} = \frac{6s^2+1}{6s^2} = Z_{22}, \quad Z_{12} = Z_{21} = 3s\right]$$

7. For the given circuit, find A, B, C and D parameters

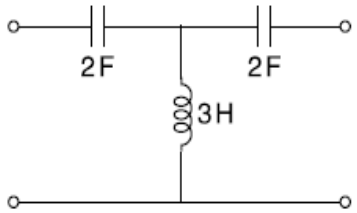

Figure 11.41

$$\left[\text{Ans. } \begin{matrix} \frac{6s^2+1}{6s^2} & \frac{12s^2+1}{12s^2} \\ \frac{1}{3s} & \frac{6s^2+1}{6s^2} \end{matrix}\right]$$

8. A two-port network has parameters

$A = D = 0.98$ and $B = j60\ \Omega$. Find the ratio

$\frac{V_2}{V_1}$ if $I_2 = 0$

[**Ans.** – 0.98]

9. Find Z-parameters

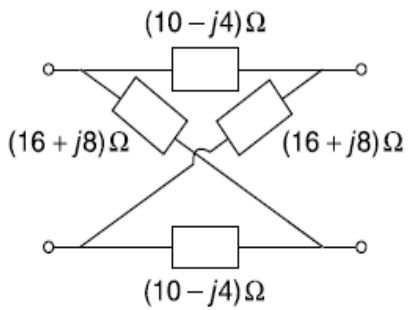

Figure 11.42

$$\left[\text{Ans. } \begin{matrix} 13+j2 & 3+j6 \\ 3+j6 & 13+j2 \end{matrix}\right]$$